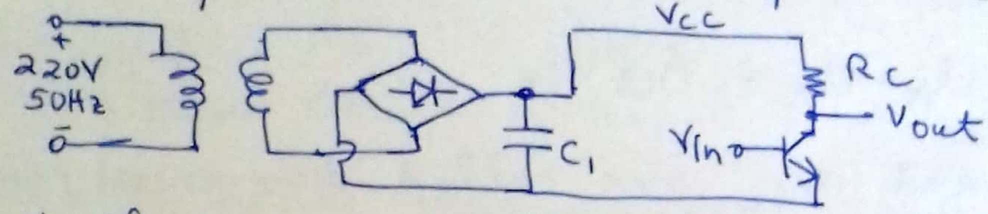
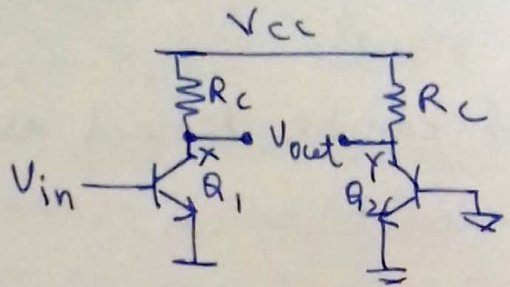
DIFFERENTIAL AMPLIFIER

* Recall the rectifier circuit studied in "Introduction to Electronics". If that circuit powers a CE amplifier as shown below, then the 50Hz power-supply hum would show up in the output.



* What if we do the following:-



$v_x = A_v v_{in} + v_r$

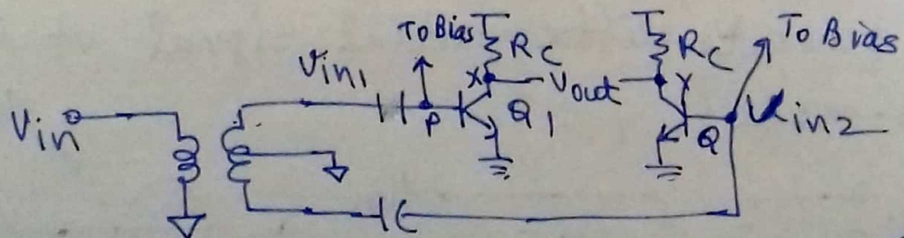
$v_y = v_r$

where, v_r is the power supply ripple.

The noise on V_{CC}, which is the power supply hum would get cancelled out, giving us a clean output voltage.

Thus, $\quad v_x - v_y = V_{out} = A_v v_{in}.$

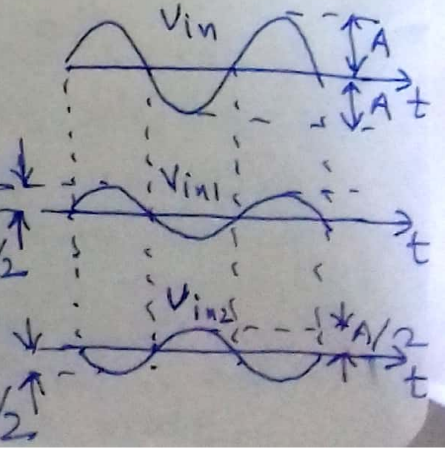
* Instead of grounding the base of Q_2 above (Keep in mind AC ground) can we do something different. What if we do the following,



How do v_{in1} and v_{in2} look?

⇒ v_{in1} and v_{in2} are out-of-phase?

⇒ Amplitude of v_{in1} and v_{in2} are same but half of amplitude of v_{in}.



Thus, $v_{in} = -v_{in2}$. and

$$v_x = A_v v_{in1} + v_r.$$

$$v_y = -A_v v_{in2} + v_r.$$

$$\Rightarrow v_x - v_y = A_v v_{in} \quad \because |v_{in1}| = |v_{in2}| = \left|\frac{v_{in}}{2}\right|$$

* v_{in1} and v_{in2} are called differential signal and the transformer generates differential signal from single-ended signal.
* A differential signal can be defined as follows:-

$$V_1 = V_0 \sin(\omega t) + V_{CM}$$

$$V_2 = -V_0 \sin(\omega t) + V_{CM}$$

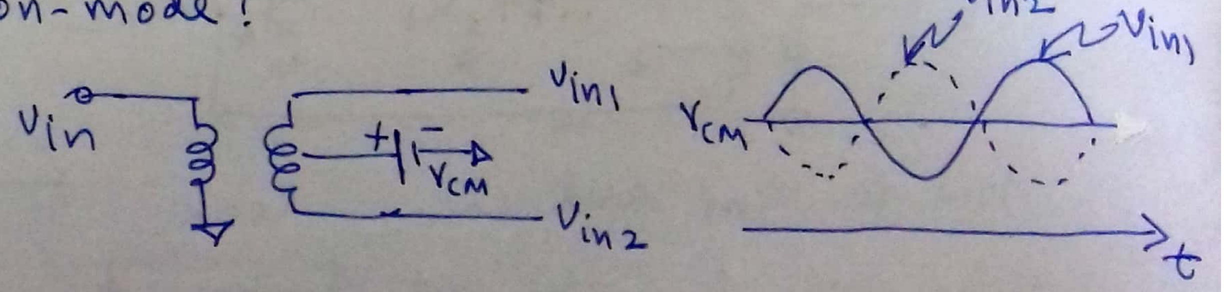
where, V_1 and V_2 are differential signal

V_0 is the amplitude of V_1 and V_2

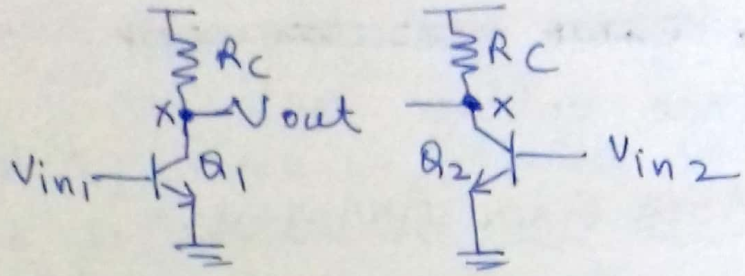
V_{CM} is the DC level over which the AC signal rides. and is therefore called common-mode (CM)

* $(V_1 - V_2)$ has a total peak-to-peak differential swing of $4V_0$.

* How to generate differential signal of different common-mode?



* Psuedo-Differential Amplifier:-

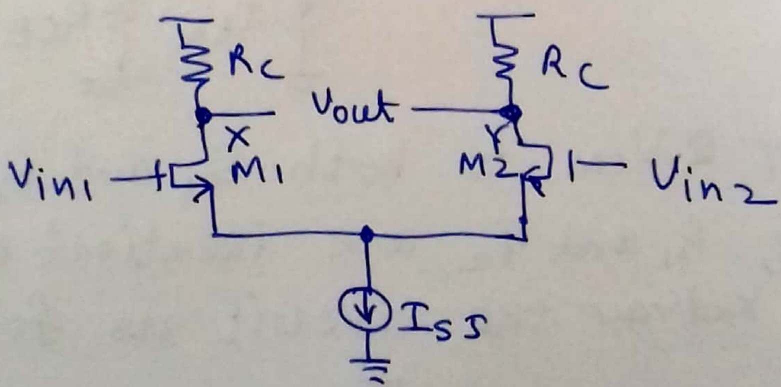


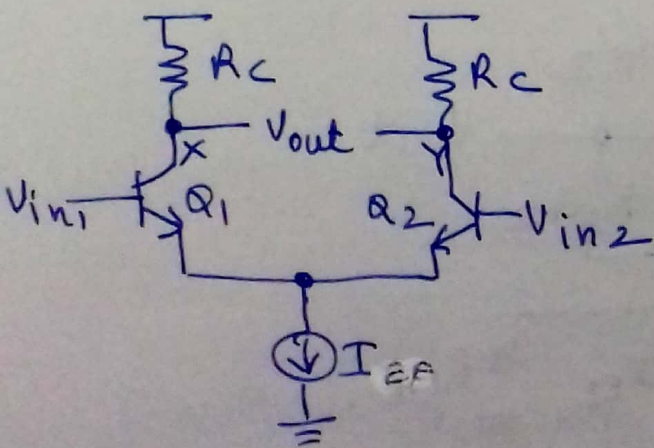
→ Here input CM is approx. 0.7V. $= V_{be,on}$.

→ If I_c is the bias current flowing through Q_1 and Q_2 then output CM is $V_{cc} - I_c R_c$.

→ If input CM changes by 20mV then bias current changes by 2.2 times and output CM changes to $(V_{cc} - 2.2 I_c R_c) \Rightarrow$ a drastic change as it would compromise the output voltage swing. Why?? Recall swing limitations in CE and CS amplifier.

* HOW DO YOU MAKE THE OUTPUT CM INSENSITIVE TO INPUT COMMON MODE:-



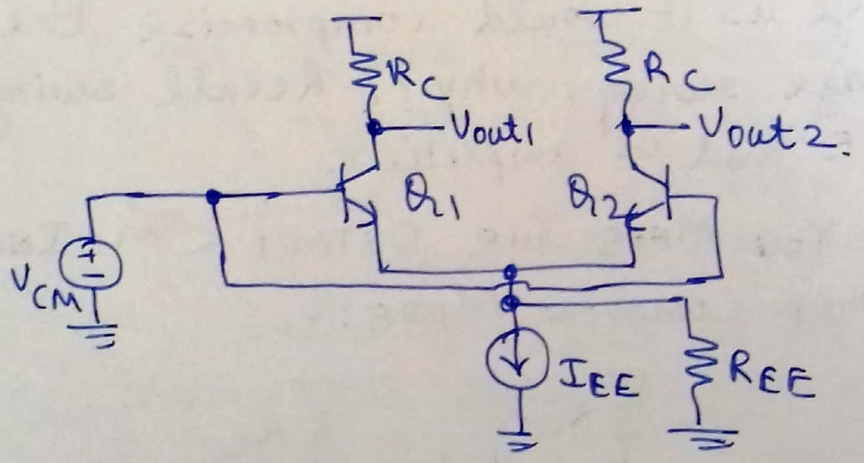


* ADD a tail current source as shown here.
* In order to ensure that Output CM is insensitive to Input CM we have to make sure that M_1, M_2 are in saturation and Q_1, Q_2 are in active mode.

* Also, we have to make sure that I_{SS} and I_{EE} have their compliance voltage met.

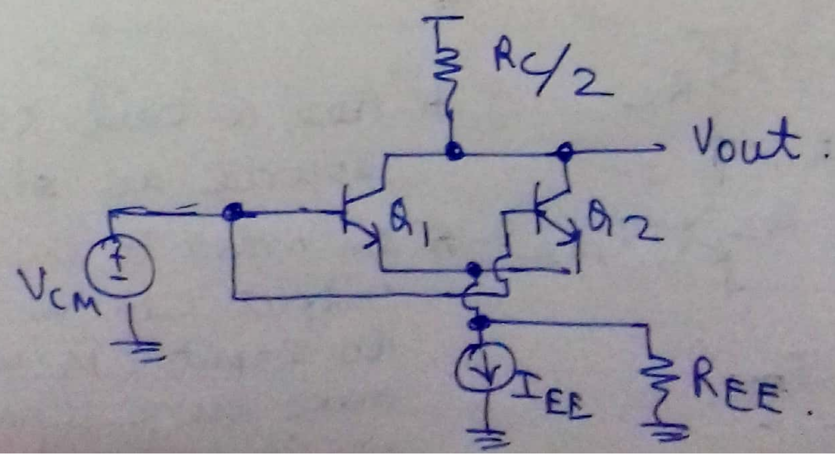
COMMON MODE GAIN ANALYSIS:-

* Ideally the differential amplifier is insensitive to input CM variation.
* However, if the tail current source has finite impedance then the output CM changes with variation in input CM.
* In-order to analyze input CM response we do the following:-



⇒ Apply V_{CM} to both Q_1 and Q_2.

⇒ Since, Q_1 and Q_2 are identical ~~and~~ then we can redraw the circuit as follows:-



Thus,

$$A_{CM} = \frac{V_{out}}{V_{CM}} = \frac{2g_{m1,2}}{1+2g_{m1,2}R_{EE}} \cdot \frac{R_C}{2}.$$

as, Q_1 and Q_2 come in parallel and the combination is degenerated by R_{EE}.

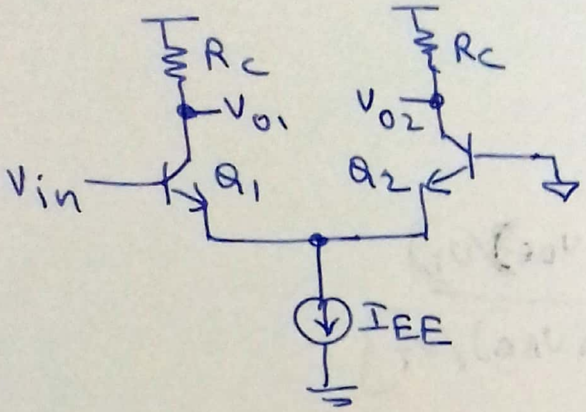
* For the same amplifier, differential mode gain is,

$$A_{DM} = +g_{m1,2} R_C.$$

NOTE :- Sign of the gain does not matter because of the differential nature of the input and output.

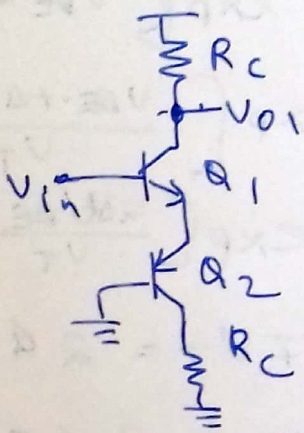
Types of Differential Amplifiers:-
* Differential - to - Differential.
* single-ended - to - Differential. → Passive using transformer
* Differential - to - Single - ended.

Analysis of Single-ended to Differential.



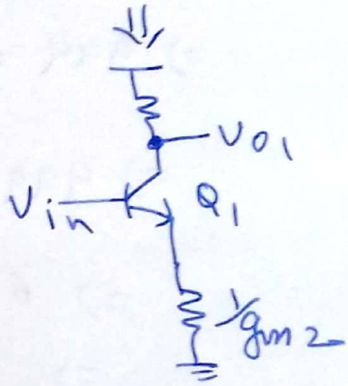
$V_{out} = (V_{o1} - V_{o2})$.

For swing at V_{o1} ⇒



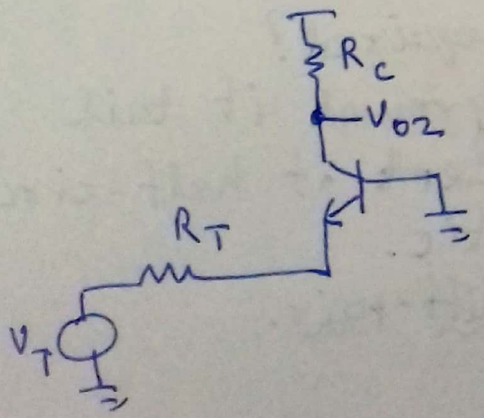
If $V_A = \infty$ then

⇓



$$\therefore \frac{V_{o1}}{V_{in}} = \frac{-R_C}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}}$$

For swing at V_{o2} we do this,



* $V_T = V_{in}$ as it is an emitter follower.
* $R_T = 1/g_{m1}$.

$$\therefore \frac{V_{o2}}{V_{in}} = \frac{R_C}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}}.$$

$$\therefore \frac{V_{o1} - V_{o2}}{V_{in}} = \frac{V_{out}}{V_{in}} = -\frac{2R_C}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}} = -g_m R_C$$